



MAGIC detection of VHE γ -ray emission from NGC 1275 and IC 310

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Abstract: The MAGIC Cherenkov telescopes observed the Perseus cluster sky region in stereo mode for nearly 90 hr from October 2009 to February 2011. This campaign led to the discovery of very high energy γ -ray emission from the central radio galaxy NGC 1275 and the head-tail radio galaxy IC 310. Here we report the results on the most recent discovery of NGC 1275 which was detected at low energies in the 2010/2011 data. We also present latest results on IC 310, which had been detected in the 2009/2010 data.

Keywords: active galactic nuclei, NGC 1275, IC 310, Perseus, very high energy γ -rays, MAGIC

1 Introduction

Most of the previously known ~ 45 extragalactic very high energy (VHE) γ -ray emitters are blazars, the few exceptions being two radio galaxies, M 87 [1] and Cen A [2], and two starburst galaxies, NGC 253 [3] and M82 [4]. The two galaxies NGC 1275 and IC 310 recently discovered by the MAGIC telescopes in the Perseus cluster (redshift $z = 0.018$) do not easily fit to any of the known VHE emitter classes.

NGC 1275 is the central galaxy of the Perseus cluster and its classification varies between different papers and catalogues. It was included in the original Seyfert catalogue [5], but already flagged to be unusual because of its complex structure. After the introduction of Seyfert 1 and 2 subclasses by Khachikian and Weedman [6], NGC 1275 was labeled as Sy2. Few years later, Veron proposed it to be a BL Lac [7], but in his latest catalogue NGC 1275 is classified as Sy1.5 [8]. The complex structure of NGC 1275 including surrounding filaments leads to a peculiar morphology classification [9]. Additionally, another galaxy called High Velocity System is moving towards NGC 1275 along the line of sight. Recent observations show that a collision between the two galaxies has not started yet [10].

IC 310 is classified as head tail radio galaxy, a type of active galactic nuclei only occurring in dense galaxy clusters

like the Perseus one. Due to the fast movement of IC 310 relative to the cluster, the friction between the jet with the intra-cluster medium (ICM) causes a strong bending of the jets [11, 12]. In 1999 it was suggested that IC 310 could be a dim blazar because of the absence of strong emission lines and the spectral indices on radio and X-ray measurements [13]. Later on it was also shown that the X-ray emission may originate from the central active galactic nucleus of a BL Lac-type object [14].

The *Fermi*-LAT measured high energy γ -rays from NGC 1275 up to 25 GeV [15] and detected strong flaring activity in July 2010 [16]. Additionally, an analysis of *Fermi* data resulted in a detection of IC 310 for energies above 30 GeV [17].

2 MAGIC Observations

The MAGIC (Major Atmospheric Gamma Imaging Cherenkov) experiment consists of two 17 meter Imaging Air Cherenkov telescopes located at the Canary Island of La Palma, at 2200 meters a.s.l., working in stereoscopic mode since the autumn 2009. The MAGIC telescopes are currently the largest world-wide existing Imaging Atmospheric Cherenkov Telescopes (IACTs), leading to a low energy threshold of ~ 50 GeV. Depending on the energy of the primary particle, the system has an

energy resolution of 15-25% and a angular resolution of $0.05\text{--}0.12^\circ$. The telescopes have a field of view of 3.5° and can turn to any position faster than 40 s. The sensitivity of the MAGIC telescopes is $\sim 0.8\%$ of the Crab Nebula flux above ~ 250 GeV in 50h of observation time [18].

The MAGIC experiment observed the central part of the Perseus cluster for ~ 25 hr in 2008, when only the first telescope was operating (mono data). This survey resulted in upper limits on VHE γ -ray emission above 100 GeV from NGC 1275, intra-cluster cosmic rays and dark matter annihilations [19].

The stereo observation campaign on NGC 1275 and on the central part of the Perseus cluster took place from October 2009 to February 2011, during dark nights and observing the source at the lowest possible zenith angles, which guaranteed a low energy threshold. The data can be divided in two main samples, corresponding respectively to the observational seasons from October 2009 to February 2010, and from August 2010 to February 2011. During the first season, ~ 45 hr of observation time were accumulated using two wobble [20] positions offset by 0.4° in RA with respect to NGC 1275. Since the commissioning of the stereo trigger system was still ongoing, the observations were carried out in the so-called *soft stereo mode*, i.e. using the MAGIC-I trigger system and reading out the second telescope simultaneously. This results in slightly higher threshold, but allows a partially independent mono analysis. Conversely, for the second season, the full stereo trigger and four wobble pointing positions equally distributed around NGC 1275 were used. With this settings, a higher sensitivity and a better coverage of the central part of the Perseus cluster were achieved. Additional ~ 45 hr of observation time were added to the previous 2009/2010 dataset.

3 Data Analysis and Results

The analysis of the data was performed with the standard MAGIC reconstruction and analysis software [21]. Due to the different trigger conditions used in the two seasons, the datasets had to be analyzed separately. The overall stereo campaign resulted in the detection at VHE of both NGC 1275 and IC 310, as shown in the significance skymap above 150 GeV in figure 1. In the following, we report the main MAGIC results achieved so far on these two sources.

3.1 IC 310

IC 310 was serendipitously discovered in the field of view of the NGC 1275 observation during the 2009/2010 survey. Due to angular acceptance reason, only one of the two wobble pointing position datasets was used for the detection and for the flux estimation of the source, resulting in ~ 20 hr of observation time. The source was detected both in mono and stereo mode, and it was the first source dis-

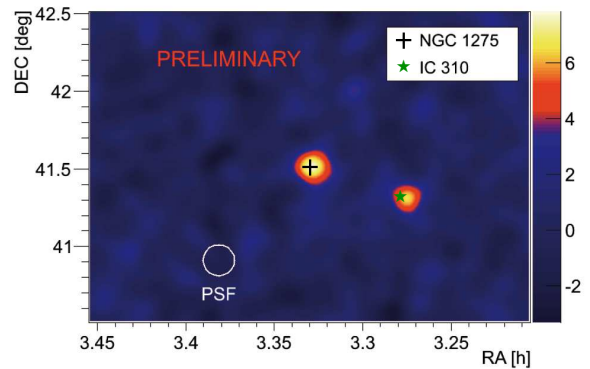


Figure 1: Significance skymap above 150 GeV of the Perseus cluster region. For this map the overall MAGIC stereo data from October 2009 to February 2011 have been combined. NGC 1275 and IC 310 are clearly detected by MAGIC.

covered by MAGIC using stereoscopy.

The spectrum obtained from these data combined with results from Fermi shows an unusual hard spectral index $\Gamma \sim -2.00$ in an energy range between 2 GeV and 7 TeV, without any hint of a cut-off (see figure 2). The lightcurve

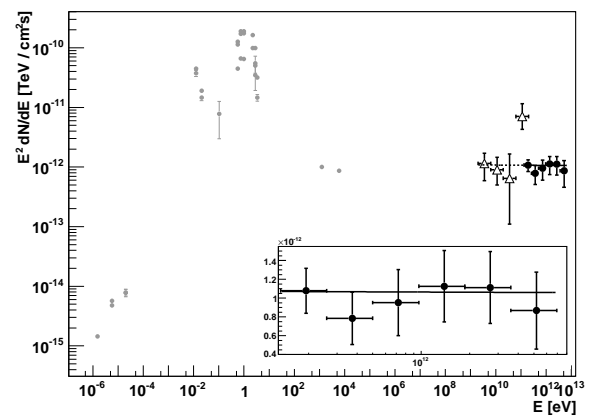


Figure 2: Spectral energy distribution of IC 310 obtained with 20.6 hr of MAGIC stereo data (full circles). Open triangles show the flux measurements from the *Fermi*-LAT from its first two years of operation. Archival X-ray, optical, IR and radio data obtained from the NED database are shown with dots. The solid line shows a power-law fit to the MAGIC data, and the dotted line is its extrapolation to the GeV energies. A zoom-in of the MAGIC points is also shown [22].

obtained from 2008 to 2010 mono and stereo datasets shows a strong hint of variability, as reported in figure 3. A preliminary analysis of the 2010/2011 data confirms the variability of the source (on year scale) since the object shows significantly weaker VHE emissions in this period. This is displayed in figure 4, where the significance skymap above 100 GeV (from data taken between August

2010 and February 2011) shows a point-like emission from NGC 1275, whereas no hint of signal coming from IC 310 is present. The estimation from the 2010/2011 dataset of the flux and the lightcurve of IC 310 is still ongoing.

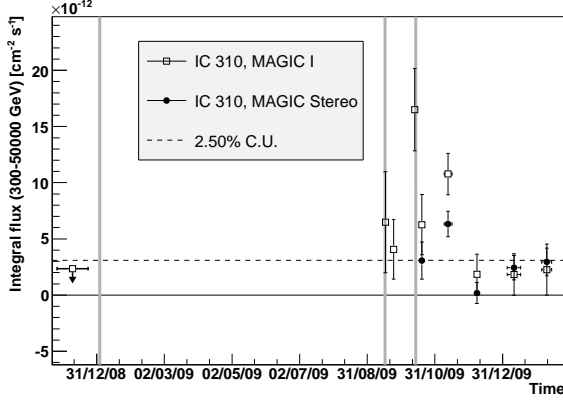


Figure 3: Lightcurve (in 10 day bins) of the γ -ray emission of IC 310 above 300 GeV obtained with the mono (open squares) and the stereo (full circles) MAGIC data from 2009/2010 campaign. The open square with an arrow is the upper limit on the emission achieved from mono data taken between November and December 2008. Vertical gray lines show the arrival times of >100 GeV photons from the *Fermi*-LAT instrument. The horizontal dashed line is a flux level of 2.5% Crab Units (C.U.) [22].

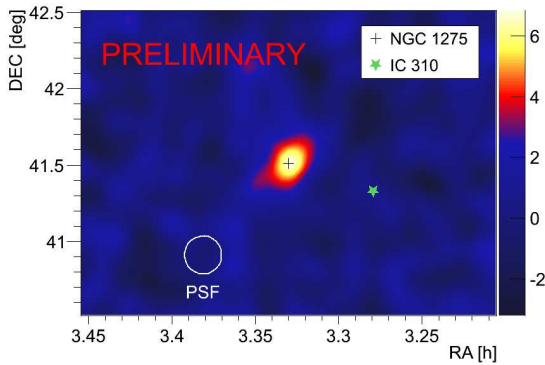


Figure 4: Significance skymap above 100 GeV of the Perseus cluster region. For this map the MAGIC stereo data from August 2010 to February 2011 have been used. NGC 1275 is clearly detected at the center of the cluster, while IC 310 is not visible at VHE.

3.2 NGC 1275

The 2009/2010 data analysis showed a hint of VHE emission from NGC 1275. The data taken was continued in August 2010 which finally resulted in the detection of the source in October 2010, announced in the ATel#2916. In

figure 5, the θ^2 plot above 100 GeV from the 2010/2011 survey (after data selection) is shown: a clear γ -ray emission at $\sim 6.6\sigma$ level is detected (see also figure 4). The signal decreases rapidly with energy and vanishes above approximately 600 GeV [23].

The unfolded spectrum of NGC1275 is shown in figure 4. It can be fitted with a power law with a very soft index of about -4.

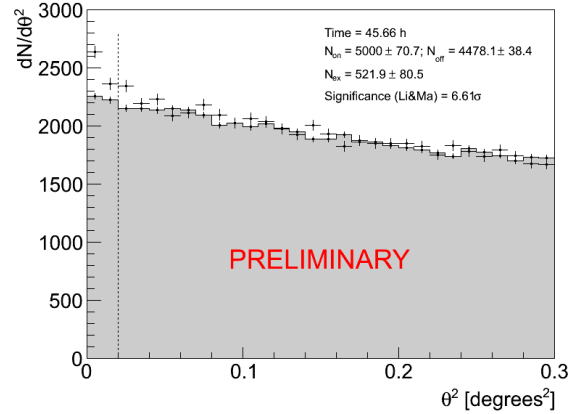


Figure 5: MAGIC stereo θ^2 plot of NGC 1275 above 100 GeV from 2010/2011 stereo data. The black points represent the *signal* while the gray shaded region is the *background*. The vertical dotted line defines the *signal region* below which we integrate the signal and calculate the background. A clear signal at $\sim 6.6\sigma$ level is detected.

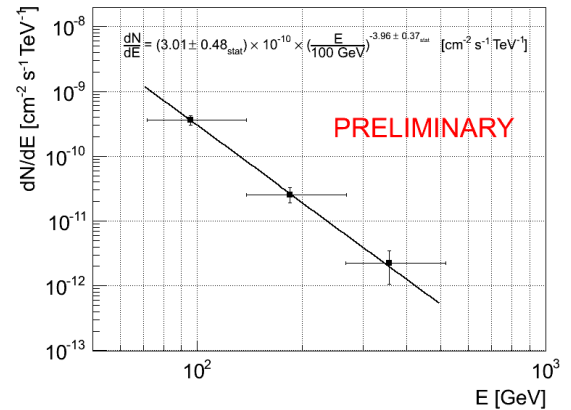


Figure 6: MAGIC unfolded stereo spectrum of NGC 1275 using data from 2010/2011. The spectrum is fitted by a power law with very soft index of about -4. Due to the unfolding process the points and errors are partially correlated.

4 Discussion

We have reported the current results on the galaxies IC 310 and NGC 1275 achieved from the MAGIC stereo observations of the Perseus galaxy cluster region. The two sources have been detected respectively in 2009/2010 and 2010/2011 dataset.

With IC 310 being significantly weaker in the season 2010/11 (see Figure 4) than in the previous season, the variability of the source is proven. This excludes the emission mechanism via bow shock model as proposed by Neronov *et al.* [17], and favours the emission mechanism to be BL Lac like, where a part of the inner jets points towards Earth.

The detection of NGC 1275 was achieved thanks to excellent sensitivity of the MAGIC telescopes around ~ 100 GeV, which makes MAGIC the leading ground-based instrument currently operating at those energies. A detailed estimation of the spectrum and lightcurve of the source is still ongoing and will give the possibility to test models of active galactic nuclei. Additionally, as NGC 1275 is the main foreground for intracluster cosmic ray and dark matter searches, a detailed knowledge of the spectrum allows a better understanding of the cluster itself. A detailed description of the Perseus cluster and its physics can be found in [23].

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